

**Comparison of a Modified Double Poling Ergometer for Cross Country Skiers with
Disabilities**

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ABSTRACT

The purpose of this study was to compare physiological variables (i.e. oxygen consumption, blood lactate, heart rate, respiratory exchange ratio) during exercise on a double poling ergometer modified for sit skiers to a field test for the same skiers. Three male and four female athletes from the Canadian National / Developmental team (17-54 years of age, ranging in ability from a complete T7 spinal injury to cerebral palsy) completed a field test and a double poling ergometer protocol separated by at least 24 hours. Both protocols consisted of three maximal sets of skiing of three minutes duration per set separated by approximately one and a half minutes rest. A wireless metabolic system (Sensormedics, VmaxST or Cosmed, K4b²) and heart rate monitor were used to measure physiological responses during each test. Arterialized blood lactate was measured before and after each set and for 15 minutes post exercise. There were no significant differences between the field and ergometer tests for peak oxygen consumption (VO_2 peak) (field = 35 ± 6 mL/kg/min vs. ergometer = 33 ± 7 mL/kg/min; $p = 0.491$). However, significantly higher peak heart rate (field = 173 ± 5 bpm vs. ergometer = 178 ± 4 bpm; $p = 0.046$) and respiratory exchange ratio (RER) (field = 1.2 ± 0.1 vs. ergometer = 1.4 ± 0.1 ; $p = 0.022$) were found during the double poling ergometer protocol. There were no significant differences in blood lactate at baseline and after set one between protocols. However, a significantly higher lactate was found after set two (field = 7 ± 4 mmol/L vs. ergometer = 12 ± 5 mmol/L; $p < 0.001$) and set three (field = 8 ± 3 mmol/L vs. ergometer = 13 ± 4 mmol/L; $p = 0.001$) during the ergometer protocol compared to the field test. There were moderate correlations between the field and double poling ergometer for VO_2 peak ($r = 0.79$; $p = 0.035$), and peak blood lactate ($r = 0.83$; $p =$

0.02). However, no correlations were found between protocols for peak heart rate ($r = 0.37$; $p=0.491$) and RER ($r = 0.54$; $p= 0.207$). Results of this study suggest that the double poling ergometer is similar to a field test for evaluating VO_2 peak in elite cross country sit skiing athletes; however, the ergometer test involves a higher heart rate and anaerobic component.

TABLE OF CONTENTS

PERMISSION TO USE.....	ii
ACKNOWLEDGEMENTS.....	iii
ABSTRACT.....	iv
TABLE OF CONTENTS.....	vi
LIST OF TABLES.....	ix
LIST OF FIGURES.....	x
LIST OF APPENDICES.....	xii
CHAPTER 1 SCIENTIFIC FRAMEWORK.....	1
1.1 Introduction.....	1
1.2 Review of Literature.....	3
1.2.1 Brief History.....	3
1.2.2 Classifying Sit Skiers.....	4
1.2.3 Equipment for Regular Cross-Country Skiing and Sit Skiing.....	5
1.2.4 Technique.....	6
1.2.5 Physiology of Cross Country Skiers.....	11
1.2.6 Aerobic and Anaerobic Contributions to Performance.....	12
1.2.7 Sport Specificity.....	16
1.2.8 Physiological Differences between Able and Disabled Athletes.....	18
1.3 Statement of the Problem and Hypothesis.....	21
1.3.1 Statement of the Problem.....	21
1.3.2 Hypothesis.....	21
1.4 Limitations and Delimitations.....	22

1.4.1	Limitations.....	22
1.4.2	Delimitations.....	22
CHAPTER 2	METHODS.....	23
2.1	Research Design.....	23
2.2	Participants Characteristics.....	23
2.3	Procedures.....	24
2.3.1	Test Protocol.....	24
2.3.2	V _O ₂ peak, Respiratory Exchange Ratio, and Pulmonary Ventilation.....	26
2.3.3	Heart Rate.....	27
2.3.4	Blood Lactate Concentration.....	27
2.4	Statistical Analyses.....	30
CHAPTER 3	RESULTS.....	31
3.1	Results.....	31
3.1.1	Peak V _O ₂	32
3.1.2	Peak Heart Rate.....	34
3.1.3	Peak Oxygen Pulse.....	35
3.1.4	Peak Respiratory Exchange Ratio.....	36
3.1.5	Peak Respiratory Rate and Minute Ventilation.....	37
3.1.6	Blood Lactate Concentrations.....	39
CHAPTER 4	DISCUSSION.....	41
4.1	Discussion.....	41
4.1.1	Field versus Ergometer.....	42
4.1.1.1	Peak V _O ₂	42

4.1.1.2 Heart rate and Oxygen Pulse.....	43
4.1.1.3 Pulmonary Ventilation.....	44
4.1.1.4 Blood Lactate and Respiratory Exchange Ratio.....	45
4.1.2 Sit Skiing versus Standing Skiing.....	48
4.1.3 Physiological Measures and Performance.....	51
4.3 Limitations.....	51
4.4 Recommendations for Future Research.....	52
CHAPTER 5 SUMMARY AND CONCLUSIONS.....	54
5.1 Summary.....	54
5.2 Conclusions.....	55
REFERENCES.....	56
APPENDICES.....	65

LIST OF TABLES

2.1 Subject Characteristics.....	24
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LIST OF FIGURES

Figure 1.1	Equipment (Skies, Sled, Poles).....	7
Figure 1.2	Modified Double Poling Cross-Country Ski Ergometer.....	20
Figure 2.3	Metabolic and Heart Rate Set-up.....	29
Figure 3.1	Oxygen consumption (VO_2) measured in a representative individual during the field and double poling ergometer protocol (3 X 3min)...	31
Figure 3.2	(A) Mean values for relative VO_2 values \pm standard deviations. (B) Individual values for relative VO_2 between the field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for relative VO_2.....	32
Figure 3.3	(A) Mean values for absolute VO_2 values \pm standard deviations. (B) Individual values for absolute VO_2 between the field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for absolute VO_2.....	33
Figure 3.4	(A) Mean values for peak heart rate values \pm standard deviations. (B) Individual values for peak heart rate between field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for peak heart rate.....	34
Figure 3.5	(A) Mean values for oxygen pulse \pm standard deviations. (B) Individual values for oxygen pulse between the field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for oxygen pulse.....	35
Figure 3.6	(A) Mean values for respiratory exchange ratio \pm standard deviations. (B) Individual values for respiratory exchange ratio between the field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for peak respiratory exchange ratio...	36
Figure 3.7	(A) Mean values for respiratory rate \pm standard deviations. (B) Individual values for respiratory rate between field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for peak respiratory rate.....	37
Figure 3.8:	(A) Mean values for minute ventilation \pm standard deviations. (B) Individual values for minute ventilation between the field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for peak minute ventilation.....	38

Figure 3.9	Mean blood lactate values during various time points \pm standard error.....	39
Figure 3.10	Individual blood lactate results.....	40

LIST OF APPENDICES

APPENDIX A	Classifications.....	66
APPENDIX B	Ethics: Certificate of Approval.....	68
APPENDIX C	Consent Form.....	70
APPENDIX D	Example of a Subject Information Sheet.....	75

CHAPTER 1

SCIENTIFIC FRAMEWORK

1.1 Introduction

Cross-country skiing has long been a popular activity, with over 16 million individuals worldwide and more than 5 million individuals in North America regularly participating (Hixson, 1981; Karlsson, 1984; MacDougall et al., 1979; Smith et al., 1996). Cross country skiing is characterized by repeated dynamic contractions over an extended period of time, requires a high level of sustained power output by both the upper and lower body (Bergh, 1987; Faria, et al., 1996; Hoffman & Clifford, 1992; Karlsson, 1984; Nesser et al., 2004; Wisloff & Helgerud, 1998), and has been described as a classic example of an endurance activity (Karlsson, 1984).

Success in cross-country skiing requires genetic endowment and specific physiological traits (Brooks et al., 2000). One physiological trait that has been associated with cross-country skiing success is maximal oxygen consumption ($\text{VO}_2 \text{ max}$) (Baumgartl, 1990; Bergh, 1987; Berg & Forsberg, 1992; Bilodeau et al., 1996; Ingjer, 1991; Karlsson, 1984; Ng et al., 1988; Niinimaa, et al., 1978; Rundell & Bacharach, 1995; Rusko, 1992; Staib, et al., 2000). $\text{VO}_2 \text{ max}$ is defined as the “maximum amount of oxygen that an organism can be stimulated to extract from the atmosphere and then transport to and use in tissue (muscle)” (Thoden, 1991, p.108). $\text{VO}_2 \text{ max}$ is often measured in a laboratory setting using an ergometer, due to the technical problems related to testing in the field, such as

cold temperatures, inclinations, and snow conditions (Haug et al., 1999; Noakes, 2000; Thoden, 1991, p. 118; Verges et al., 2003). The most common ergometers used to evaluate athletes include treadmills, cycle ergometers, and arm crank ergometers (Haug et al., 1999; Verges, et al., 2003). Testing for sports other than running or cycling, therefore, lack specificity when using these ergometers (Allin & Lockwood, 2004; Mygind et al 1991; Wisloff & Helgerud, 1998). Mode of exercise for training and testing is extremely important because VO_2 max reflects both the individual's ability to transport oxygen and the specific muscle's ability to utilize it (Mygind et al., 1991; Thoden, 1991, p.118). Clausen (1976) demonstrated that peak oxygen consumption, measured on small muscle groups, can change considerably with training, without any commensurate changes in VO_2 max when measured on a treadmill.

Recently, a cross-country ski ergometer has been designed to accommodate cross-country skiers with disabilities (sit skiers). Given the importance of peak oxygen uptake and sport specific testing, we evaluated a modified double poling cross country sit ski ergometer used by elite athletes with disabilities by comparing physiological parameters (oxygen uptake, heart rate, oxygen pulse, respiratory exchange ratio, pulmonary ventilation and blood lactate) measured on the ergometer to the same parameters measured during a field test. Due to the uniqueness of cross-country skiers with disabilities, this thesis will first give a general description of sit skiing (which will include a brief history, classifications, equipment, and technique) followed by a review of the physiology of cross-country skiing, the importance of VO_2 max and specificity of lab tests.

1.2 Review of Literature

1.2.1 Brief History

Scholars maintain that cross-country skiing originated in Fennoscandian countries (Norway, Sweden, Denmark, and Finland) in prehistoric times over 4000 years ago (Clifford, 1992; Karlsson, 1984). Cross-country skiing was first used as a means to increase mobility over deep snow to improve hunting (Clifford, 1992; Karlsson, 1984). It was not until the 19th century that skiing competitions came into existence, starting in Norway. The famous Holmenkollen (Oslo) ski festival started in 1892. At first, the main focus of these Nordic festivals was the Nordic combined event: cross-country skiing and ski jumping. In 1900, a separate cross-country race was held at the Holmenkollen. From this point on cross-country skiing has grown in popularity world-wide (Hixon, 1981). Over the years, skiing has grown to include individuals of all ages and abilities (Karlsson, 1984). Disabled skiing initially began over 50 years ago as a unique form of physical therapy and rehabilitation for veterans of World War One (Karlsson, 1984; Parr, 2002).

“Skiing allows an excitement and fluidity of motion, rarely accessible to persons with a disability. It provides an opportunity to develop a skill, mastery of which helps develop the personal confidence required to face, accept, and challenge the realities of day to day living” (Cross-Country Ski Canada, 2007).

Like traditional skiing, disabled skiing has evolved into an enjoyable recreational pursuit for people of all abilities and ages. Inevitably, recreation gave birth to sport, and disabled cross-country skiing is now a prevailing sport in the winter Paralympics. Disabled cross-country skiing (which includes athletes with visual impairments, cerebral

palsy, spinal cord injuries and/or amputees) appeared at the 1976 inaugural Paralympic Winter Games in Örnköldsvik, Sweden. Cross country sit skiing was first introduced at the IV Paralympic Winter Games in 1988 in Innsbruck, Austria. At the last Paralympics in Torino, Italy 13 countries competed in cross country sit skiing in six events, ranging from 2.5 to 15 kilometers. Canada won two bronze medals and had six top ten finishes. In 2010, Canada is hosting the winter Paralympics, adding to the pressure and excitement for these athletes to be successful at home; therefore, having a better understanding of the physiological characteristics of these athletes and providing a valid and specific dry land training and testing device may assist these athletes in meeting their goals.

1.2.2 Classifying Sit Skiers

In international competitions, athletes with different disabilities are classified according to their individual functional capabilities so that they can compete on an equal basis (Bhambhani et al., 2002; International Paralympic Nordic Skiing Committee, 2006). This enables athletes with similar capabilities but not necessarily similar medical disabilities (e.g. cerebral palsy or complete T7 spinal injury) to compete in the same class (Kofsky et al., 1986; Shephard, 1990; Sherrill, 1999). The International Paralympic Nordic Skiing Committee (I.P.N.S.C.) utilizes a combined medical and functional approach to classify athletes. The classification procedure involves an examination of the medical records as well as direct observation of the athlete to evaluate the functional capacity and identify the anatomic level of lesion (Bhambhani et al., 2002; International Paralympic Nordic Skiing Committee, 2006). The classification of athletes occurs during a 1 to 3 day period prior to the Paralympics. This classification procedure involves testing with the athlete

strapped to a test board. Three graded tests are used to assess trunk function, hip function, and buttock sensibility according to the American Spinal Injury Association classification. The first test involves the athlete being strapped at the hip joint, the second test involves the athlete being strapped over the knees, and the third test involves the athlete being strapped over the ankle. During each test the athlete is then asked to move about the joint being testing and is graded based on a four-point scale: a score of zero indicates no function and that the test is impossible while a score of three implies normal function. Trained classifiers conduct objective tests to evaluate trunk and limb movements as well as the strength of specific muscle groups to classify each athlete. The degree of sensory loss, presence of muscle spasticity, and use of orthotics are also taken into account in the classification process (Bhambhani et al., 2002), as shown in Appendix A. Based on the classification of an athlete, a percentage system is used. The percentage system is an adjusted time formula, which is used to determine overall place of each competitor relative to all other disabled racers. This formula assigns a percentage to each competitor based on each individual's particular disabled race class. The athlete's actual time is multiplied by this percentage to determine his/her adjusted finishing time. The percentages system is evaluated after every season by the I.P.N.S.C. (International Paralympic Nordic Skiing Committee, 2006).

1.2.3 Equipment for Regular Cross-country Skiing and Sit-skiing

Traditionally all of the equipment for regular cross-country skiing was made of natural materials: wooden skis and bamboo poles with leather hand straps (Karlsson, 1984).

Footwear was usually sturdy leather boots with thick soles. Cross country ski bindings

evolved from simple straps made of twisted wood-based thread to the “Kandahar” binding with the fastening of both the boot’s front and back to the “Rat Trap” front only binding, which is today known as the *Nordic norm*, and now has evolved into various modern bindings (Clifford, 1992).

The Nordic sit ski consists of a sitting device mounted on a pair of cross-country skis, as shown in figure 1.1. The skis are similar to standard skis, although are shorter, and are attached to the chair with a standard cross-country ski binding. The material and shape of the Nordic sit-ski is not subject to any regulations. However, the maximum allowable distance between the buttocks and the top of the skis is 30cm. Mounted steering devices are not allowed, however, competitors may use straps to fasten their bodies to the sit-ski for stabilization (International Paralympic Nordic Ski Committee, 2006).

1.2.4 Technique

Cross country skiing is defined as a cyclic sport, in which skiing velocity is derived from the distance the body travels during each cycle and the number of times the body moves through a complete cycle during one second (Bilodeau et al., 1996). Cross-country sit skiing requires participants to use their arms to propel themselves along the trail, typically using a double poling technique. There is currently no research on sit skiing double poling technique specifically; however, several studies have examined this technique in standing able bodied skiers (Bilodeau et al., 1996; Faria et al., 1996; Holmberg, et al, 2005; Leirdal et al., 2006; Millet et al., 1998; Smith, 1990 & 1992).



Figure 1.1: Equipment (Skis, Sled, Poles)

In standing skiers double poling is typically used under fast conditions or on moderate down-hills where a glide phase would occur following poling (Holmberg et al., 2005). Several studies have demonstrated that double poling is in fact more economical on flat terrain compared to diagonal striding or classical skiing (Coyle et al. 1998, Hoffman et al., 1990; Hoffman and Clifford, 1992; Rusko, 2003). Hoffman and Clifford (1990) concluded that the double poling technique was significantly more economical ($P < 0.05$) than skating or kick double poling, as demonstrated by a 12% lower oxygen consumption in trained cross country skiers. Hoffman and Clifford (1992) further supported these findings by demonstrating significantly lower oxygen consumption compared to the diagonal stride technique (26% lower) in elite cross country skiers; however, they found significantly higher lactate concentrations during double poling compared to other techniques, suggesting a higher anaerobic component. Watts and colleagues (1993) found contradictory results showing no differences in lactate values in six elite cross country skiers between double poling and diagonal striding on roller skies. On uphill terrain, where glide after poling would involve rapidly decreasing speed, double poling is infrequently used due to the high frequency and relatively large forces required. Millet and colleagues (1998, 1998) examined the kinetic and kinematic aspects of double poling on speed and inclinations. They demonstrated that increases in speed were achieved by increasing pole force and cycle rate accompanied by a shortening of both poling and recovery time in each cycle. Furthermore, they found inclination to have a significant effect on poling forces and time-related variables that is, an unchanged poling phase duration and shortened recovery phase duration on steeper inclinations. Sit skiers use the

double poling technique exclusively, which may result in an altered physiological response compared to standing skiers.

Double poling technique is typically broken down into three phases: the pole plant, the poling phase, and the recovery phase (Holmberg et al., 2005). The pole plant is used as a preparation for the poling phase. Holmberg and colleagues (2005) analyzed the double poling technique and found a clear pattern for the pole plant phase in elite able bodied cross country skiers. All skiers began in a high starting position with extended hip, knee, and ankle joints and a forward shift in body weight. They found a positive correlation between a high heel before pole plant position and both peak ($r=0.82$) and impulse of pole force ($r=0.76$). In addition peak pole force correlated positively to double poling velocity ($r=0.70$). In high speed double poling, at pole plant the shoulder is flexed slightly beyond mid-range and then extends throughout poling (Smith et al., 1996). The pole plant should be as vertical as possible (Smith et al., 1996). Smith and colleagues (1996) demonstrated that faster skiers began the poling phase with the poles closer to vertical compared to slower skiers. Elbow flexion followed by extension is associated with triceps eccentric activity which may enhance force development followed by triceps concentric activity during elbow extension in later poling phase (Hoffman and Clifford, 1992; Smith et al., 1996).

The second phase after the pole plant is the poling phase (Holmberg et al., 2005). During this phase, skiers flex the elbow, hip, knee, and ankle joints with angle minima occurring around the point of peak poling force after approximately one third of the poling phase

(Holmberg et al., 2005). From the high pole plant position the center of gravity is lowered. This allows high peak poling forces to be applied to the pole. Body mass itself and the active downward acceleration of the center of gravity provide the two external forces on the pole (Holmberg et al. 2005). Assuming a functional trunk during the poling phase, air drag force is slightly reduced and reduces the drag coefficient on the skies (Leirdal, et al., 2006). The third phase or recovery phase involves the extension of the hip, knee, and ankle joint in preparation for the pole plant (Holmberg et al., 2005).

Double poling is typically considered primarily an upper body exercise; however, there is mounting evidence that in able body skiers the legs provide the main energy source (Holmberg et al., 2005 & 2006; Van Hall et al., 2003). Holmberg and colleagues (2006) investigated the contributions of the legs to double poling performance in elite skiers. They locked the knee and ankle joint to minimize the use of the legs. Maximal double poling velocity was 9.4% greater in the unlocked condition compared to the locked condition and time to exhaustion in an incremental test was 11.7% longer. The incremental test used was a continuous progressive protocol at a constant inclination of 1°, starting at 9 km/h and increasing 3 km/h every work period of 4 minutes with 1 minute of rest. They also found a significantly lower VO_2 peak (7.7%) in the locked condition. Interestingly there was no difference in lactate responses between the two conditions. This research provides insight into the potential physiological and biomechanical differences between able-bodied skiers and sit skiers; however, the contribution of the legs were only minimized in this study, therefore the results may be underestimated.

Pilot data in our laboratory has shown that sit ski athletes (n=4) compared to standing athletes (n=4) produce a lower power per stroke (Sit skiers: 177 ± 53 vs. Standing skiers: 280 ± 62 watts, $p < 0.05$), a shorter stroke length (Sit skiers: 113 ± 12 vs. Standing skiers: 146 ± 13 cm, $p < 0.05$), and a non-significant, but higher stroke rate (Sit skiers: 57 ± 9 vs. Standing skiers: 52 ± 7 strokes per minute, $p = 0.46$) during a 1 minute critical power test. Research examining the relationship between cycle length, stroke rate, and skiing velocity in standing skiers has clearly demonstrated that performance is highly correlated to cycle length but not correlated to cycle rate either on flat (Bioldeau et al., 1992; Dillman, et al., 1979; Marino, et al., 1980; Norman, et al., 1985; Norman et al., 1987; Roy & Barbeau, 1990) or on uphill terrain (Bioldeau et al., 1992; Norman et al., 1987, 1989). Future research is needed to examine the biomechanical differences in double poling technique between sit skiing and standing skiing athletes.

1.2.5 Physiology of Cross Country Skiers

As previously described, cross-country skiing is characterized by repeated dynamic contractions of a number of muscles over a prolonged period of time and requires a high level of sustained power output by both the upper and lower body (Bergh, 1987; Hoffman & Clifford, 1992; Wisloff & Helgerud, 1998). One physiological parameter that has consistently demonstrated a high correlation with cross-country skiing performance is maximal oxygen consumption ($\text{VO}_2 \text{ max}$) (Bilodeau et al., 1996; Ingjer, 1991; Karlsson, 1984; Larsson et al., 2002; Morrissey et al., 1987; Niinamäa, et al., 1990; Smith et al., 1996; Staib, et al., 2000; Rundell & Bacharach, 1995). $\text{VO}_2 \text{ max}$ is defined as the “maximum amount of oxygen that an organism can be stimulated to extract from the

atmosphere and then transport to and use in tissue (muscle)” (Thoden, 1991, p.108), while peak oxygen consumption (VO_2 peak) is often used to describe the highest obtainable VO_2 consumption during specific modes of exercise. Tests that measure VO_2 max have a high relevance to sports that depend on high aerobic capacities (Thoden, 1991). Cross-country skiing is a classic example of an endurance activity (Karlsson, 1984), as it requires a strong and efficient aerobic system (Morrissey et al., 1987), and utilizes the upper arm musculature during the poling action. Cross-country skiing has led to some of the highest VO_2 values recorded in athletes (Smith et al., 1996). Ingjer and colleagues (1991) reported very high values and a narrow range in VO_2 max in male world class skiers, suggesting that an extremely high VO_2 max is a prerequisite to become a world class skier. Gross VO_2 max values of elite cross country skiers have been reported to be 90 to 95 ml/kg/min (5.5 to 6.5 L/min) in males and 73-79 ml/kg/min (4.0 to 5.0 L/min) in females (Bergh, et al., 1978; Ingjer, et al., 1991; Karlsson, 1984; Rusko, 2003).

1.2.6 Aerobic and Anaerobic Contributions to Performance

Cross-country skiing typically exhibits an extremely high aerobic contribution to overall energy production; depending on the duration and intensity (e.g. uphill and downhill) of the event (the aerobic contribution ranges from 50% during 1 km sprints to 99% during 30-50 km races) (Gjellesvik, 2006; Karlsson, 1984; Rusko, 2003). Anaerobic energy is supplied via glycolysis and the breakdown of phosphocreatine (PCr) stores. PCr stores quickly deplete within the 1st minute of exercise by 30-70% (Rusko, 2003), therefore high intensity exercise, which exceeds VO_2 peak relies on anaerobic glycolysis for

energy production. During short steep uphill skiing; the oxygen demand has been calculated to increase up to 100-120 ml/kg/min exceeding VO_2 max (Rusko, 2003). Glycolysis is the breakdown of glucose resulting in the production of ATP, pyruvate, lactate, and H^+ . If there is limited oxygen, the rate of oxidative phosphorylation may be reduced and the contribution of anaerobic glycolysis is increased. Lactate is used in the adjacent muscle fibers and is also transported to the blood. Lactate is removed from the blood to less active muscles and the heart, where it is used for oxidative energy production. An increase in blood lactate therefore suggests an increase in glycolysis or decreased removal by other tissues. Increased levels of lactate have been associated with fatigue, although the cause of fatigue is more likely related to an accumulation of acidosis, however, research has demonstrated a strong relationship between lactate and acidosis (Robergs, 2006). Recent studies have found that acidosis has little direct effect on isometric force production, maximum shortening velocity, or the rate of glycogen breakdown in mammalian muscles studied at physiological temperatures (Brooks et al., 2000). However, acidosis may cause fatigue by inhibiting oxidative phosphorylation, or by indirectly causing fatigue. For instance, extracellular acidosis may activate group III-IV nerve afferents in muscle and hence may be involved in the sensation of discomfort in fatigue (Brooks et al., 2000). Despite the fact that anaerobic metabolism is important, aerobic breakdown of carbohydrates and fats is the primary energy source during cross-country skiing. Carbohydrates and fats are first broken down in the sarcoplasm of muscle fibers to smaller molecules, which are transported into the mitochondria where the reactions catalyzed by the mitochondrial enzymes produce large amounts of ATP. Carbon dioxide (CO_2) produced during the breakdown of fuels is a byproduct of

oxidative metabolism and venous blood transports CO₂ to the lungs. Substrate utilization (carbohydrates and/or fats) depends greatly on the duration of the race and on the diet before the race (Rusko, 2003). Respiratory exchange ratio is derived from the amount of CO₂ produced divided by the amount of oxygen consumed and is an indirect measure of substrate utilization (as the ratio approaches and surpasses 1.00, carbohydrates are considered the primary fuel source). Previous research has shown that carbohydrate loading increases muscle glycogen and results in a higher respiratory exchange ratio (Havemann et al., 2006).

With the shared contribution of aerobic and anaerobic energy systems, it is important to note that maximal oxygen uptake is only one of several surrogates affecting performance in cross-country skiing. Other factors such as muscular strength (Gaskill, et al., 1999; Karlsson, 1984; Mygind, et al, 1991; Nesser et al., 2004; Ng, et al., 1988; Norman et al., 1989; Rundell & Bacharach, 1995; Shorter et al., 1991), blood lactate accumulation (Baumgartl, 1990; Karlsson, 1984; Larsson et al., 2002; Rundell & Bacharach, 1995), pulmonary ventilation (Rusko, 2003), and substrate utilization (Rusko, 2003) have all been found to be significant predictors of skiing performance. Nonetheless, VO₂ peak is still the most common parameter used to assess performance capabilities in cross-country skiers (Bunc et al., 1987; Niinimaa et al., 1978). Demment and colleagues (1988) reported that VO₂ peak was an important determinant for success, although they evaluated whole body VO₂ using a treadmill protocol, thus the results may be underestimated. Stromme and colleague (1977) found that female and male skiers achieved 2.9 and 3.1 percent higher VO₂ max values when skiing uphill, as opposed to

running, respectively. More specifically to sit skiing, several studies have concluded that upper body VO_2 peak in able bodied cross country skiers is important to performance (Mygind et al., 1991; Sharkey & Heidel, 1981; Staib et al., 2000; Watts et al., 1993). Staib and colleagues (2000) examined the relationship between aerobic and anaerobic double poling power and performance in elite cross-country skiers. Significant relationships ($p < 0.05$) were identified between double poling time to exhaustion ($r = -0.80$), double poling VO_2 peak ($r = -0.74$), and upper body power expressed in watts ($r = -0.68$). Further analysis indicated that 75% of the variance in International Ski Federation points could be accounted for by double poling VO_2 peak ($\text{ml/kg}^{-2/3}/\text{min}$) and upper body power, with double poling VO_2 peak exhibiting the highest beta. Mygind and colleagues (1991) further observed a high correlation between race performance (time) in cross-country skiing and a double poling ergometer VO_2 peak in able-bodied athletes ($r = -0.80$). Despite the importance of VO_2 peak to performance in able bodied cross country skiers (Haymes & Dickinson, 1980), to our knowledge, no research has been conducted on skiers with disabilities, even though cross country skiing has greatly increased in popularity in athletes with disabilities, and has evolved into a prominent winter Paralympic event. At the Paralympics, female sit skiers race over three distances: 2.5, 5, and 10 kilometers ranging in time from approximately 8.5 to 31 minutes in duration, and male sit skiers race over three distances as well: 5, 10, and 15 kilometers ranging in time from approximately 15.5 to 42 minutes in duration (these times are based on results from the Winter Paralympic results in Torino, Italy 2007).

1.2.7 Sport Specificity

Recently, a double poling ergometer (WEBA-Sport cross country ski ergometer, Liesneckgasse, Austria) has been designed to accommodate cross-country sit skiers with disabilities, as shown in figure 1.2. The double poling ergometer pulling stand was shortened by three feet and each individuals' sled could be securely fastened to the base, accommodating cross-country sit skiers. Typically, disabled cross-country skiers train during the spring/summer months on a ski ergometer that uses ropes attached to pulleys. The skier pulls on handles attached to the ropes, which are attached to a resistance, to simulate the motions that the skier would use in an actual outdoor ski race. Several studies have stressed that testing should be specific because of the very specific muscular, circulatory and metabolic adaptations (Bilodeau et al, 1995; Mygind, et al., 1991; Rundell et al., 1995), suggesting the importance of an ergometer providing similar physiological stress as outdoor racing. Training specificity is a very important training principle as shown by Clausen (1976) who demonstrated that peak oxygen uptake, measured on small muscle groups, can change considerably with training, without any commensurate changes in whole body VO_2 max when measured on a running treadmill (Clausen, 1976; Holmer, 1974). Mygind and colleagues (1991) measured VO_2 on a treadmill and on a double poling ergometer to evaluate which test correlated best with cross country skiing performance. There was no significant correlation for VO_2 values between the treadmill and double poling ergometer and only the double poling ergometer VO_2 correlated significantly ($r=-0.80$, $p<0.05$) with performance. Typically, arm crank ergometers are the most commonly used modality in assessing VO_2 in upper body testing (Wisloff & Helgerud, 1998). The criticism of this ergometer when testing cross country skiers is that

it has a different movement pattern and does not include all relevant muscle groups used in cross country skiing. Mygind and colleagues (1991) found marked differences in VO_2 peak on a poling ergometer for skiers with approximately the same VO_2 peak on an arm crank ergometer. Recently Holmberg and colleagues (2006) found that in elite cross country skiers, VO_2 peak during an arm crank was only 86% of their VO_2 peak obtained from a double poling ergometer protocol (3.98 ± 0.4 vs. 4.65 ± 0.6 L/min; $p > 0.05$, respectively). They explained the differences by the amount of active muscle mass, suggesting that double poling is more than just an upper body exercise (Holmberg et al., 2006), and concluded that the arm cranking is an unspecific exercise mode for skiers. Further, Noakes (2000) states “if sports performance cannot be measured frequently with a high degree of precision in the laboratory, then training induced changes in exercise performance are not quantifiable”. These results emphasize the importance of a sport specific ergometer for testing and training aerobic capacity in cross-country skiers. However, the development of sport-specific laboratory conditions for cross country skiing has posed some problems for scientists (Rusko, 2003), as it is difficult to simulate such factors as temperature, inclination, speed, and snow conditions (Noakes, 2000). All these factors may affect aerobic and anaerobic values in the laboratory. Wisloff and Helgerud (1998) compared a double poling field test to a double poling ergometer and found similar VO_2 peak and lactate values, however, they found significantly higher peak minute ventilation and heart rate responses during the ergometer protocol. They explained the differences by the fact that subjects worked under different ambient conditions. The ambient temperature in the laboratory was 20°C and -5°C during the field tests. They also suggested a possibility of more dynamical work with the legs in the

field test thereby increasing the venous return and increasing stroke volume compared with work on the ski ergometer where the legs were more secured.

In able-bodied athletes, cross country skiing double poling ergometers have been reported as reliable when measuring VO_2 peak with an intraclass correlation coefficient of 0.98 and a coefficient of variation of 2.5% (Wisloff & Helgerud, 1998). As well, double poling has been reported to be valid based on similar VO_2 peak values ($p=0.24$) on an ergometer compared to a field test (Wisloff & Helgerud, 1998). In addition, it has been shown that VO_2 peak testing of upper body work has a good association between tests and performance in able-bodied athletes (Bilodeau et al., 1995; Mygind et al., 1991).

1.2.8 Physiological Differences between Able and Disabled Athletes

Although double poling ergometers have been shown to be sport specific in able-bodied skiers, marked physiological differences may exist between able and disabled skiers. For example, because of the limited lower body involvement, a greater upper body power output may be required in sit skiers when compared to able-bodied skiers. VO_2 peak arm values can reach 66% to 88% of VO_2 max in standing skiers (Mygind et al., 1991). VO_2 peak values have been reported to be lower in subjects with paraplegia than in able bodied subjects due to reduced active muscle mass (Burkett et al., 1990; Van Loan et al., 1987). However, upper body VO_2 using similar muscle mass may still be lower in sit skiers due to physiological differences. Sit skiers' range in disability from cerebral palsy to complete spinal cord injuries, therefore physiological differences may depend on the specific disability. Cerebral palsy is a chronic neurological disorder caused by a static

lesion to the immature brain that is characterized by deficits in movement and postural control (Dodd et al., 2002). Because of impairments such as weakness, spasticity, and incoordination, many people with CP have difficulty with activities such as propelling their wheelchairs, running, or walking. These symptoms may suggest alterations in both performance and physiological measures (decrease oxygen uptake, blood lactate, and heart rate) (Dodd et al., 2002). Spinal cord injured athletes may also have alterations in physiological measures. Spinal cord injured athletes may exhibit lower limb blood pooling secondary to an inactive leg muscle pump and impaired autonomic control below the level of spinal lesion (Fukuoka, 2002; Hjeltnes, 1977). Both of these factors may contribute to an altered circulatory response to the upper body (Glaser, 1989; Hooker et al., 1990). Compared to able-bodied individuals, people with spinal cord injuries respond to sub-maximal and maximal arm exercise with lower stroke volumes and higher heart rates due to the decreased venous return (Brooks et al., 2000; Davis & Shephard, 1988; Hopman, 1992 & 1994; Kinzer & Convertino, 1989). Furthermore, it has been suggested that sub maximal cardiac output may also be lower and blood flow to the exercising arm muscles may be attenuated in response to diminished venous return (Davis et al., 1990; Hjeltnes, 1977). Fukuoka and colleagues (2002) demonstrated that oxygen uptake kinetics in trained spinal cord injured subjects are faster than healthy untrained subjects only in a supine position, which supports the hypothesis of an altered circulatory response from blood pooling. Future research is needed to explore the physiological differences specific in cross-country sit skiers with varying disabilities to able-bodied cross-country skiers.



Figure 1.2: Modified Double Poling Cross-Country Ski Ergometer

1.3 Statement of the Problem and Hypothesis

1.3.1 Statement of the Problem

To our knowledge, there have been no studies, which have examined cross-country skiers with physical disabilities. With the limited research, we wanted to determine a valid method to assess physiological characteristics in a laboratory setting. Therefore, the purpose of this study was to compare a lab-based test using a sit-ski double poling ergometer to a field test in elite disabled cross-country skiers. A secondary purpose was to examine the relationship between specific physiological characteristics measured on the ergometer and performance (performance was determined as the athletes' personal best time in a 5 km race). Seven elite (three males and four females) athletes were assigned to complete either a field test or a double poling ergometer protocol and then the opposite protocol on a separate day. Both protocols consisted of three maximal sets of three minute bouts separated by approximately one and a half minutes rest. A wireless metabolic system (Sensormedics, VmaxST or Cosmed, K4b²) and heart rate monitor were used to measure physiological responses during each test. Arterialized blood lactates were measured before and after each repeat and for 15 minutes post exercise.

1.3.2 Hypothesis

Our primary hypothesis is that the lab-based double poling sit-ski ergometer will result in similar physiological measurements (peak oxygen consumption, peak heart rate, oxygen pulse, respiratory rate, minute ventilation, respiratory exchange ratio, and blood lactate concentrations) when compared to a field test.

Our secondary hypothesis is that peak oxygen consumption; oxygen pulse, respiratory rate, minute ventilation, respiratory exchange ratio, and blood lactate would be negatively correlated with performance, that is, as performance time decreases the physiological variable measured will increase.

1.4 Limitations / Delimitations

1.4.1 Limitations

- (1) Results obtained from this study can only be applied to the specific populations from which the subjects were drawn.
- (2) Dietary habits were not controlled since the subjects were free-living individuals.
- (3) Due to the uniqueness of the population a small sample size was used, which may increase the chance of a type II error, that is, the chance of accepting the null hypothesis when the research hypothesis is actually true (“false negative”).

1.4.2 Delimitations

- (1) Results from this study apply to the specific age range of the subjects, their training status, health, and diet since all of these variables may affect the results.
- (2) Since the majority of the analyses performed involved the use of technical equipment, it can only be assumed that the information provided was accurate.

CHAPTER 2

METHODS

2.1 Research Design

This study used a repeated measure cross over design in which every subject was assigned to perform a field test protocol or a laboratory double poling ergometer protocol initially and then the opposite test separated by at least 24 hours. During the time of the study, all subjects were encouraged to undertake their normal training and diet. The dependent variables measured were (1) peak oxygen uptake (VO_2 peak), (2) heart rate, (3) oxygen pulse (VO_2 peak/peak heart rate), (4) pulmonary ventilation (breathing frequency and minute ventilation), (5) respiratory exchange ratio (RER), and (6) blood lactate concentration. This study was approved by the Ethics Review Board of the University of Saskatchewan, Saskatoon, Saskatchewan, Canada (Appendix B).

2.2 Participant Characteristics

Seven (3 male / 4 female) subjects, aged 17 to 54 years were recruited for this study. Subjects included Developmental and National team athletes. Subjects had competed for a minimum of two years at high level competitions; which includes national and international competitions. Four of the athletes were previously Paralympians and one athlete was a multiple Paralympic medalist. All seven subjects completed the study. Subject characteristics are shown in Table 2.1.

Table 2.1: Subject Characteristics

Subject	Class	Injury	Age-yrs	Height-cm	Weight-kg	Time-min:sec-5km	%Body Fat
M1	LW10	T10-complete	33	171	61	22:34	12
F2	LW10	T7-complete	45	173	51	20:08	14.4
F3	LW11.5	T7-complete	17	137	68	32:17	Data Missing*
M4	LW12	L1-complete	42	179	87.3	25:36	19.6
F5	LW12	CP	23	146	44	33:08	27
F6	LW11.5	L1-complete	45	165	63.2	28:40	37.5
M7	LW11	T11-complete	54	181	77.2	28:50	19
Mean			37	164.6	64.5	27:18	21.6
St. Dev			13	16.8	14.8	4:49	9.3

St. Dev = Standard Deviation

M = Male

F = Female

CP = cerebral palsy

T = Thoracic

L = Lumbar

*Subject was unable to attend body composition analysis.

2.3 Procedures

2.3.1 Test Protocol

Participants were informed as to the nature of the study and what would be required of them and written informed consent was obtained (Appendix C). During the time of the study, all subjects were encouraged to undertake their normal training and diet. They were instructed to be adequately hydrated, not to eat 2 hours prior to the test, avoid strenuous exercise and limit caffeine intake within 6 hours of testing, according to the Canadian Society of Exercise Physiology guidelines, as shown in Appendix D. Prior to testing, body weight and estimated height were measured. Body weight was measured on a Toledo scale, accurate to the nearest 0.1 kilogram. Standing height was estimated based on arm span, age, and gender ($\text{Height} = 0.75 (\text{arm span}) - 0.05 (\text{age}) + 4.04 (\text{gender}) + 40.91$) (Brown et al., 2000). Percent body fat was assessed using bioelectrical

impedance to provide more descriptive characteristics of the subjects. Each subject then completed a field test and a double poling ergometer protocol on separate days (separated by at least 24 hours). The field test was designed by the national team coaches to simulate racing conditions. The course was professionally groomed prior to testing. Both protocols consisted of a 15 minute self directed warm up, followed by three maximal sets of three minute bouts separated by one and a half minutes of rest. A three by three minute repeat was deemed acceptable to achieve VO_2 peak based on previous research (Doyon et al, 2001). Doyon and colleagues (2001) demonstrated a significant correlation ($r=0.88$) between VO_2 peak on a standardized treadmill protocol and a double poling field test with roller skis, the protocol consisted of three maximal repeats on a 640 meter course (ranging from 2-3 minutes in length) on a 2% grade. Recently a study conducted on active subjects found no difference in VO_2 peak during a 3 minute all out cycling test against fixed resistance compared to a ramp protocol (Burnley et al., 2006). Furthermore, pilot data collected in our laboratory found no significant difference between a stepwise incremental double poling ergometer protocol, starting at 25 watts and increasing 25 watts every minute until volitional fatigue, compared to a 3 minute maximal critical power test in five disabled cross country skiers (41.3 ± 7.5 ml/kg/min vs. 40.7 ± 8.3 ml/kg/min respectively; $p=0.33$). Following each exercise protocol, passive recovery was monitored for 15 minutes. Temperature and wind conditions were monitored during the field test and laboratory conditions were kept within recommended values (21 degrees Celsius) (CSEP, 1996). Blood lactate was monitored after the warm-up, after each set and post exercise (5, 10, 15 minutes). Heart rate was monitored during and post exercise with a polar heart rate monitor (Polar, Levittown, United States). A

wireless metabolic system (Sensormedic VmaxST, Conshohocken, United States, or Cosmed K4B², Rome, Italy) was used to monitor gas exchange variables (oxygen uptake, respiratory exchange ratio, breathing frequency, and minute ventilation) during exercise. Oxygen pulse is an indirect measurement of stroke volume (Bhambhani et al., 1994) and was determined as VO₂ peak (ml/min) divided by peak heart rate to denote the oxygen utilization per heart beat (Bhambhani et al., 2001).

2.3.2 VO₂ peak, Respiratory Exchange Ratio, and Pulmonary Ventilation

Indirect calorimetry was used to measure VO₂ peak, respiratory exchange ratio, breathing frequency, and minute ventilation during the field and double poling ergometer protocols, with the use of a portable wireless metabolic system (SensorMedic VmaxST or Cosmed K4b²). Prior to each testing session the portable metabolic system was calibrated using a two point calibration. Briefly, each metabolic system was calibrated against ambient air, approx. 20.93% oxygen and 0.03% carbon dioxide, and a high precision reference gas, 16% ± 0.04% oxygen and 4% ± 0.1% carbon dioxide. The turbine flow meter calibration was performed using a 3L air syringe at low, medium, and high flow velocities.

Following calibration, the proper fitting facemask to reduce air leakage, harness, and metabolic system were securely fastened to the subject, as shown in figure 2.3. The VmaxST weighs approximately 340 grams, and the Cosmed K4b² weighs approximately 500 grams. Both units are suitable for temperatures ranging from +40 to -20°C. Indirect calorimetry has been shown to have a high test-retest correlation between 0.90 and 0.95 (Kimura et al., 1990; Thoden, 1991). Specifically, the VmaxST and Cosmed K4b² have been validated against the gold standard (Douglas bag method) (Duffield et al. 2004;

McLaughlin et al. 2001) and were both found to be acceptable for measuring oxygen uptake, expired carbon dioxide, and minute ventilation over a variety of exercise intensities. Data was collected breath by breath and the results were filtered using a 20 second average and analyzed to determine if VO_2 peak values were achieved. The primary criteria used to determine if VO_2 reached peak was a plateau in VO_2 (< 0.10 L/min) during exercise over three consecutive readings. Secondary criteria included respiratory exchange ratio (VCO_2/VO_2) greater than 1.1, reaching one's age predicted and/or known maximal heart rate, and the occurrence of volitional fatigue (Chilibeck et al. 1998). Oxygen pulse was determined by taking VO_2 peak (ml/min) divided by peak heart rate.

2.3.3 Heart Rate

A heart rate monitor (Polar, Levittown, United States) was used to monitor and store heart rate every five seconds. The heart rate monitor was used according to the manufacturer guidelines. Briefly, the heart rate monitor strap was securely fastened to the transmitter and placed on the chest, just below the chest muscles and across the sternum. The grooved electrode areas were moistened and firmly pressed against the skin. The heart rate was then transmitted to the watch and stored every five seconds. The peak heart rate was recorded following each protocol.

2.3.4 Blood Lactate Concentration

Arterialized blood lactate concentration was measured before and after each repeat and for 15 minutes post exercise (5, 10, 15 minutes) with an automated lactate analyzer

(Lactate Pro, Quesnel, British Columbia, Canada). The analyzer was calibrated prior to each subject with a calibration strip and blood lactates were taken from the ear lobe according to the manufacturer's instructions. Briefly, the ear lobe was cleaned with an alcohol swab and then dried. A Softclix Pro lancet was used to prick the ear lobe and a single drop of blood was removed. The second drop of blood (approximately 5 μ L) was used for analysis. The automated lactate analyzer takes 60 seconds to analyze each drop of blood. This analyzer has been shown to be reliable and valid (Medbo et al. 2000; Saunders et al. 2005). Saunders and colleagues (2005) compared the lactate concentration determined by a laboratory gold-standard enzymatic colorimetric assay with this automated lactate analyzer. They found almost no inter variability between analyzers. They concluded that the automated lactate analyzer revealed an "outstanding correlation with the laboratory lactate determination, although the meters (lactate analyzer) were found to run 0.5 mmol/L higher than the laboratory assay." They concluded that the portable lactate analyzer is a highly accurate tool for monitoring lactate concentrations.



Figure 2.3: Metabolic and Heart Rate

2.4 Statistical Analyses

Data are expressed as means \pm standard deviations. Pearson product moment correlation coefficients were calculated to examine the relationship between pairs of variables for the field and ergometer tests and between personal best times and each variable. A paired t-test was used to determine if there were differences between means for the double poling ergometer and field test protocols for VO_2 peak, peak heart rate, peak oxygen pulse, peak respiratory exchange variable, peak minute ventilation, and peak respiratory rate. A 2 (field vs. ergometer) X 7 (baseline, after each repeat, and 5, 10, and 15 minutes post-exercise) repeated measures ANOVA was used to assess differences between conditions for blood lactate concentrations. A Tukeys post-hoc test was used to determine differences between pairs of means on this last ANOVA. Statistical significance was set at $p \leq 0.05$.

CHAPTER 3

RESULTS

There was no effect of order for the testing over the 2 days on any of the variables measured ($p < 0.05$). Figure 3.1 shows a typical VO_2 response during the two tests for a single subject. During the three maximal intervals, the subjects consistently achieved a high VO_2 response.

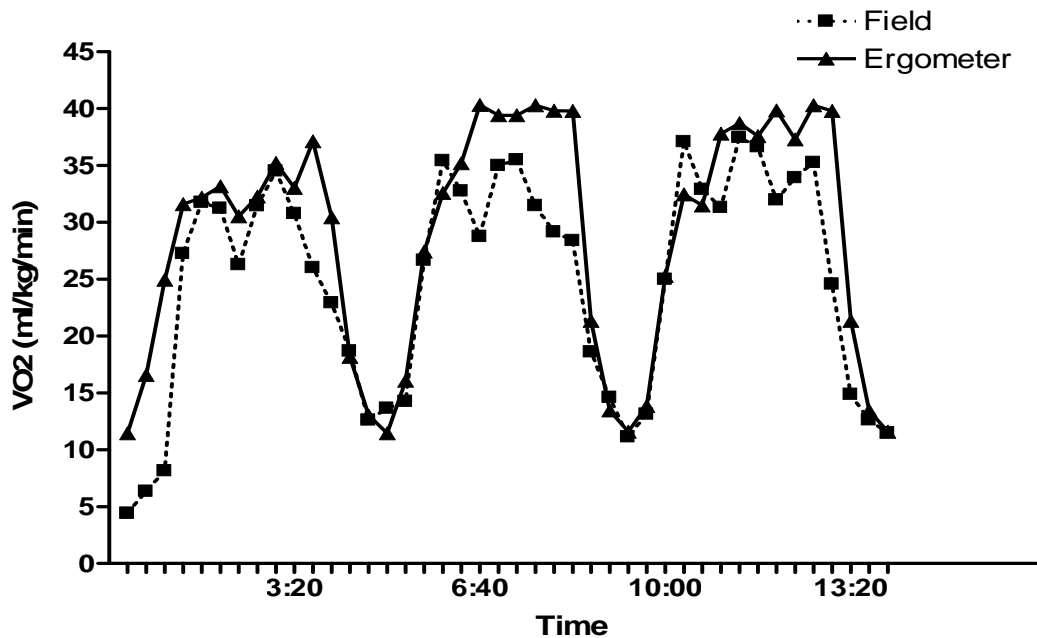


Figure 3.1: Oxygen consumption (VO_2) measured in a representative individual during the field and double poling ergometer protocol (3 X 3min). Peak values were taken as the highest average over a 20 second window during any of the three sets.

3.1.1 VO₂ Peak

There was no significant difference in relative or absolute VO₂ peak values between the double poling ergometer and the field test (Relative: Field: 34.7±5.5 vs. Ergometer: 33.4±6.9 ml/kg/min, p=0.49; Absolute: Field: 2.23±0.55 vs. Ergometer: 2.11±0.41 L/min, p=0.39) as shown in figures 3.2 and 3.3. The two protocols were moderately correlated (Relative: r=0.74, p=0.06; Absolute: r=0.79, p=0.04). Both relative and absolute peak VO₂ were moderately, however non-significantly correlated to performance (Relative: r=-0.67, p=0.095; Absolute: r=-0.69, p=0.086).

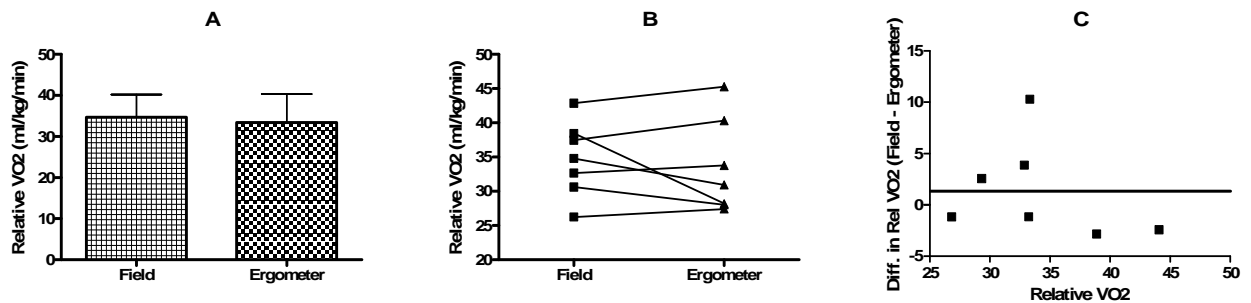


Figure 3.2: (A) Mean values for relative VO₂ values ± standard deviations. (B) Individual values for relative VO₂ between the field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for relative VO₂. Relative VO₂ is the mean between the field and ergometer protocol. The solid line indicates the mean.

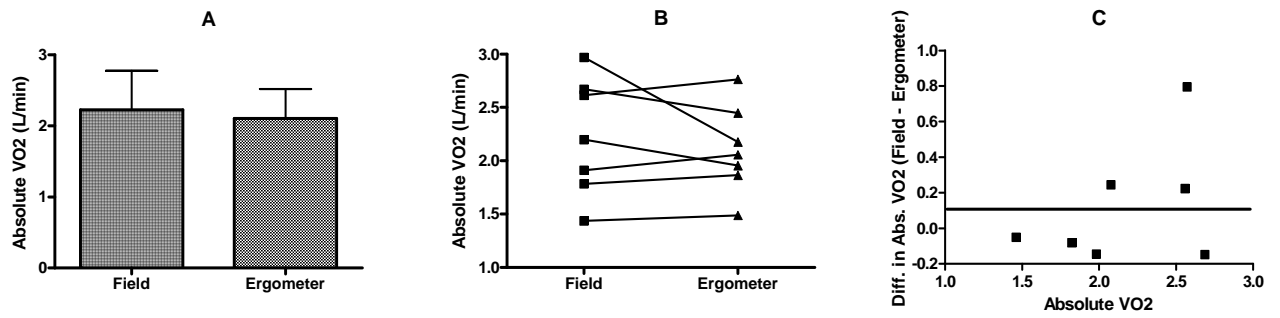


Figure 3.3: (A) Mean values for absolute VO_2 values \pm standard deviations. (B) Individual values for absolute VO_2 between the field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for absolute VO_2 . Absolute VO_2 is the mean between the field and ergometer protocol. The solid line indicates the mean.

3.1.2 Peak Heart Rate

There was a significantly higher peak heart rate during the double poling ergometer protocol compared to the field test (178 ± 4 vs. 173 ± 5 beats per minute respectively, $p=0.046$), as shown in figure 3.4(A). There was no significant correlation between the two protocols ($r=0.37$, $p=0.49$). The individual results for peak heart rate values between protocols are shown in Figure 3.4(B). There was no significant correlation between peak heart rate and performance, $r=-0.23$ ($p=0.630$).

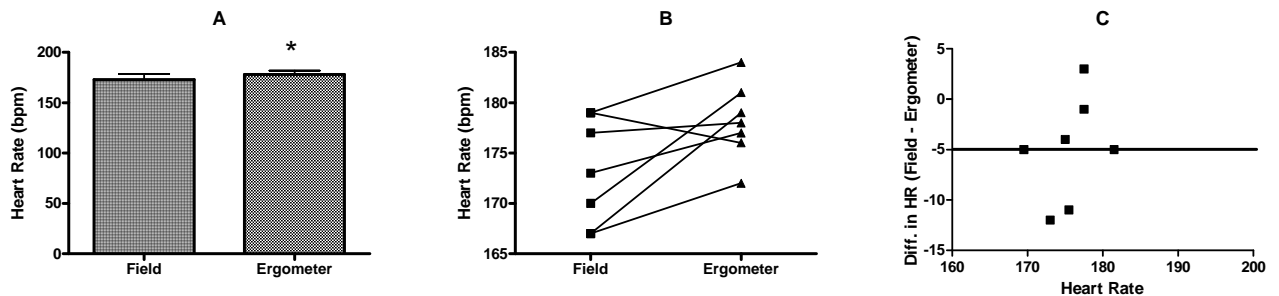


Figure 3.4: (A) Mean values for peak heart rate values \pm standard deviations. (B) Individual values for peak heart rate between field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for peak heart rate. Heart rate is the mean between the field and ergometer protocol. The solid line indicates the mean. * Indicates a significant ($p<0.05$) difference between protocols.

3.1.3 Peak Oxygen Pulse

There was no significant difference in peak oxygen pulse values between the double poling ergometer and the field test (11.8 ± 2.2 vs. 12.8 ± 3.1 VO_2 peak ml / HR peak respectively, $p=0.18$), as shown in figure 3.5(A). The two protocols were moderately correlated ($r=0.82$, $p=0.02$). The individual differences between peak oxygen pulse values between protocols are shown in Figure 3.5(B). There was a moderate however non-significant correlation between oxygen pulse and performance, $r=-0.690$, $p=0.086$.

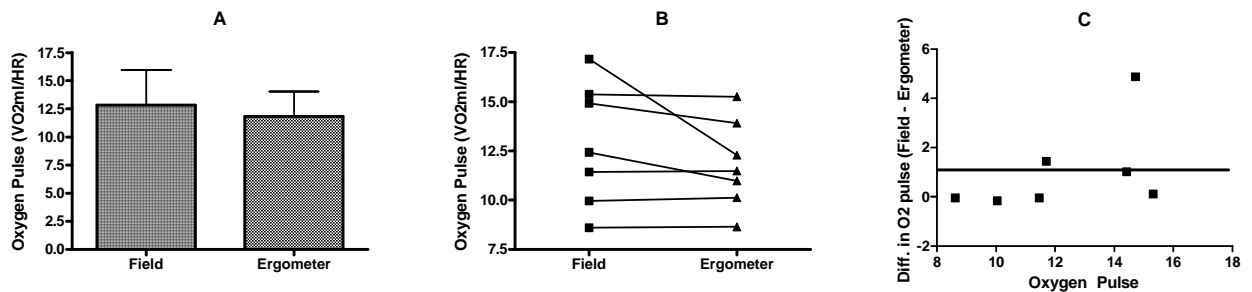


Figure 3.5: (A) Mean values for oxygen pulse \pm standard deviations. (B) Individual values for oxygen pulse between the field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for oxygen pulse. Oxygen pulse is the mean between the field and ergometer protocol. The solid line indicates the mean.

3.1.4 Peak Respiratory Exchange Ratio

There was a significantly higher peak respiratory exchange ratio during the double poling ergometer protocol compared to the field test (1.35 ± 0.15 vs. 1.19 ± 0.14 (VCO_2/VO_2) respectively, $p=0.02$), as shown in figure 3.6(A). There was no significant correlation between the two protocols for respiratory exchange ratio ($r=0.54$, $p=0.21$). The individual differences for peak respiratory exchange ratio values between protocols are shown in Figure 3.6(B). There was no significant correlation between peak respiratory exchange ratio and performance, $r=-0.090$, $p=0.847$.

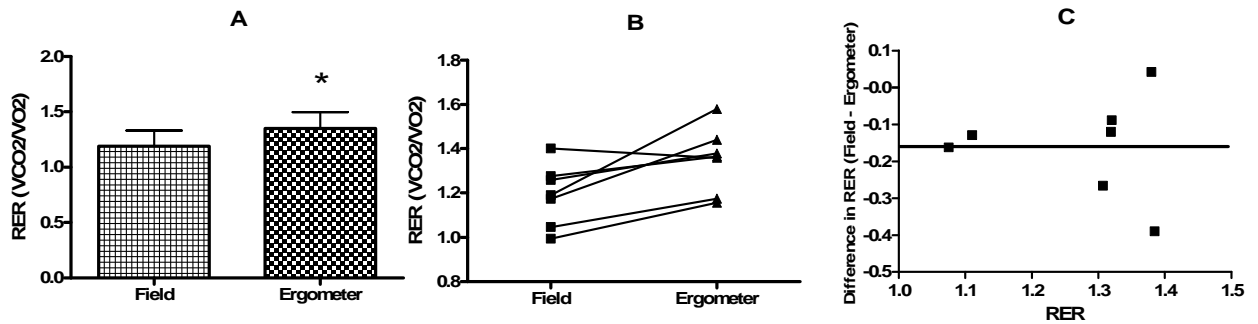


Figure 3.6: (A) Mean values for respiratory exchange ratio \pm standard deviations. (B) Individual values for respiratory exchange ratio between the field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for peak respiratory exchange ratio. Respiratory exchange ratio is the mean between the field and ergometer protocol. The solid line indicates the mean. * Indicates a significant ($p<0.05$) difference between protocols.

3.1.5 Peak Respiratory Rate and Minute Ventilation

There was no significant difference in peak respiratory rate and minute ventilation between the double poling ergometer and the field test (Peak respiratory rate: Ergometer: 62.6 ± 12.5 vs. Field: 65.9 ± 9.5 breaths per minute, $p=0.21$; Peak minute ventilation: Ergometer: 93.6 ± 23.7 vs. Field: 102.8 ± 32.8 liters per minute, $p=0.10$), as shown in figures 3.7 and 3.8. Peak respiratory rate and minute ventilation were moderately and highly correlated, respectively, between the two protocols. Peak respiratory rate: $r=0.87$, $p=0.01$ and peak minute ventilation: $r=0.95$, $p=0.001$. There was no significant correlation between peak respiratory rate or minute ventilation and performance (Peak respiratory rate: $r=0.292$, $p=0.525$; Peak minute ventilation: $r=-0.534$, $p=0.217$).

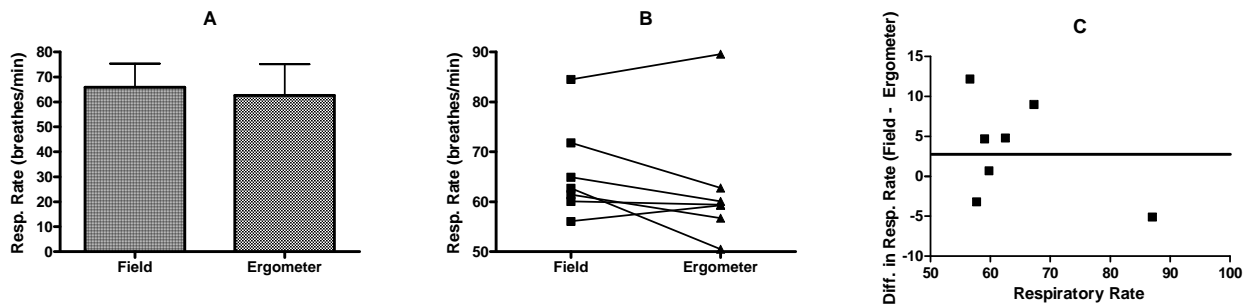


Figure 3.7: (A) Mean values for respiratory rate \pm standard deviations. (B) Individual values for respiratory rate between field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for peak respiratory rate. Respiratory rate is the mean between the field and ergometer protocol. The solid line indicates the mean.

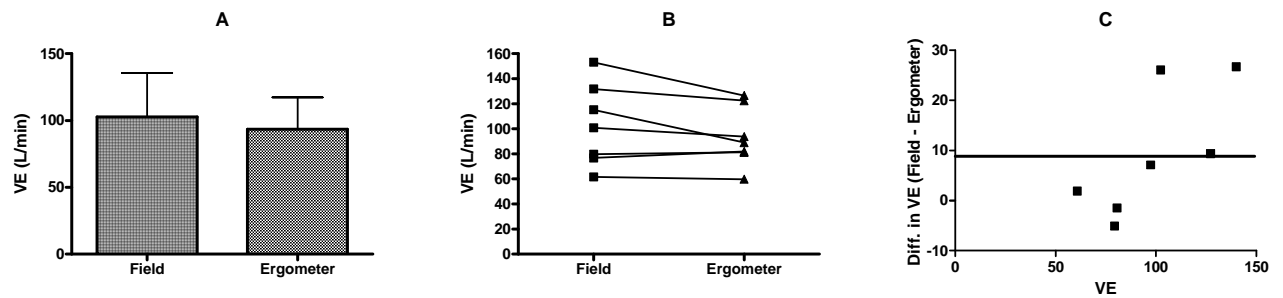


Figure 3.8: (A) Mean values for minute ventilation \pm standard deviations. (B) Individual values for minute ventilation between the field and ergometer protocols. (C) Values are the difference between the field and ergometer protocols for peak minute ventilation. Minute ventilation is the mean between the field and ergometer protocol. The solid line indicates the mean.

3.1.6 Blood Lactate Concentrations

There was a test by time interaction ($p=0.005$) for lactate during the protocols. The post hoc indicated protocols were significantly different after set 2 (Ergometer: 11.8 ± 5.1 vs. Field 6.8 ± 3.8 mmol/L, $p=0.001$) and set 3 (Ergometer: 13.0 ± 4.4 vs. Field 8.1 ± 3.1 mmol/L, $p=0.001$). There were no significant differences between protocols at baseline (Ergometer: 2.2 ± 1.4 vs. Field 2.8 ± 1.6 mmol/L, $p=1.00$), after set 1 (Ergometer 7.9 ± 4.6 vs. Field 6.1 ± 2.3 mmol/L, $p=0.84$), 5-minutes post (Ergometer: 10.4 ± 4.2 vs. Field 8.3 ± 3.4 mmol/L, $p=0.65$), 10 minutes post (Ergometer: 10.3 ± 3.8 vs. Field 7.3 ± 3.6 mmol/L, $p=0.18$), and 15-minutes post (Ergometer: 8.8 ± 3.3 vs. Field 5.9 ± 3.4 mmol/L, $p=0.19$). There was a significantly higher peak lactate during the ergometer compared to the field test (13.2 ± 4.3 vs. 9.0 ± 3.0 mmol/L, respectively, $p=0.006$), and peak lactate was moderately correlated, $r = 0.83$, $p = 0.02$. Individual results are shown in Figure 3.10. There was no significant correlation between peak blood lactate and performance, $r=0.47$, $p=0.288$.

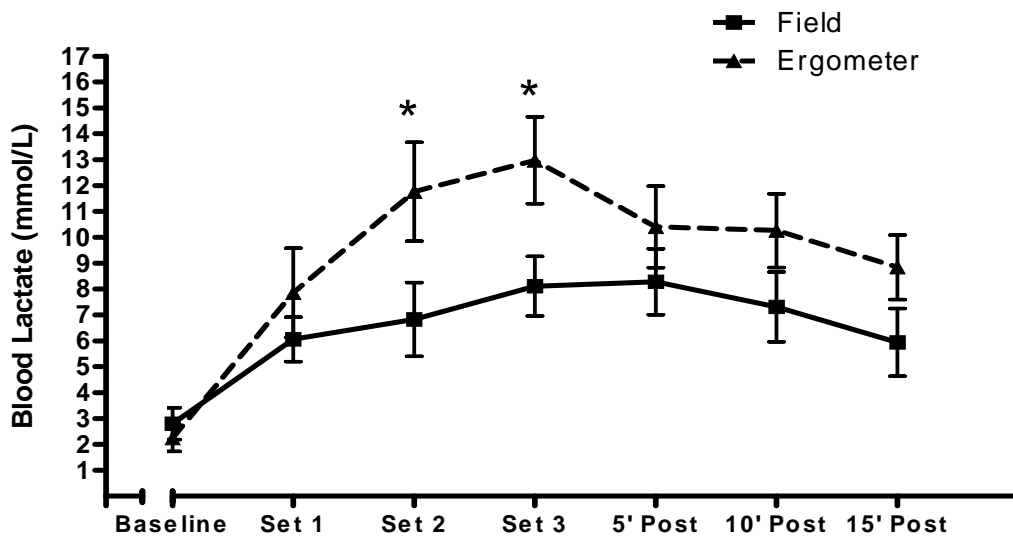


Figure 3.9: Mean blood lactate values during various time points \pm standard error. * Indicates significant ($p < 0.05$) differences between protocols.

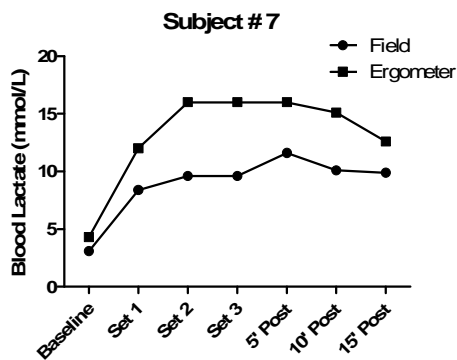
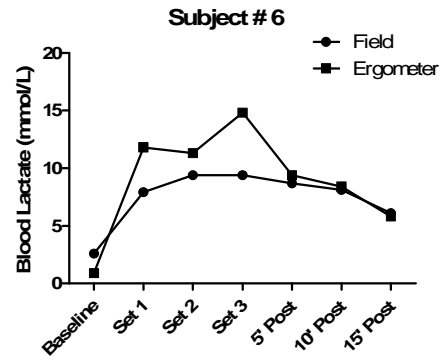
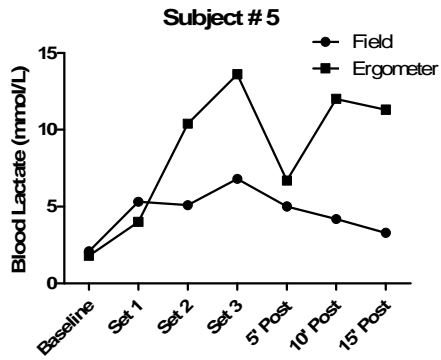
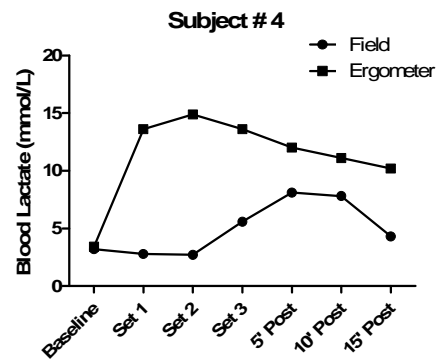
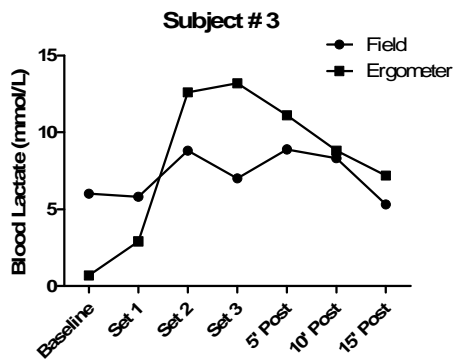
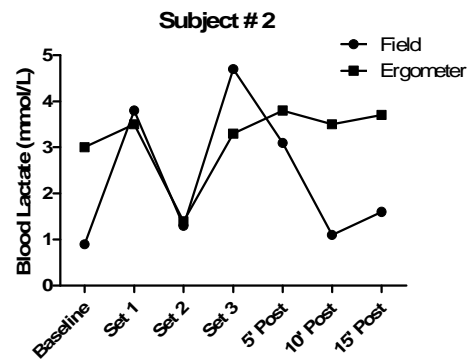
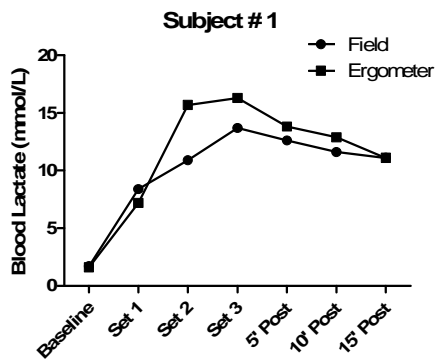


Figure 3.10: Individual blood lactate results.

CHAPTER 4

DISCUSSION

Our results partially support our hypothesis that the double poling cross country sit-ski ergometer would provide similar physiological responses (oxygen consumption, heart rates, oxygen pulse, respiratory rate, minute ventilation, respiratory exchange ratio, and blood lactate concentrations) when compared to a field test. Results showed no significant differences between the field and ergometer tests for peak relative or absolute VO_2 , minute ventilation, and respiratory rate. However, significantly higher peak heart rate, blood lactates after set 2 and set 3, and respiratory exchange ratio were found during the double poling sit-ski ergometer protocol. Furthermore, non-significant, however, moderate correlations were found between personal best performance times and peak relative and absolute VO_2 and peak oxygen pulse. Previous studies have primarily focused on different laboratory derived physiological variables and their relationship with able-bodied cross-country skiing performance (Ng, et al., 1998; Rundell, 1995; Rundell & Bacharach, 1995) or rankings (Bergh, 1987; Ingjer, 1991; Niinimaa, Dyon & Shephard, 1978; Mygind, Larsson, & Klausen, 1991; Rundell & Bacharach, 1995; Staib, Joohee, Caldwell, & Rundell, 2000). There have also been several field studies of the physiological responses to cross country skiing (Astrand & Saltin, 1961; Bioldeau, Roy, & Boulay, 1991; Doyon, Perry, Abe, & Hughson, 2001; Hoffman & Clifford, 1990; Karvonen, Kubica, Kalli, Wilk, & Krasicki, 1987; Karvonen et al., 1989; MacDougall, Hughson, Sutton, & Moroz, 1979; Mahood, Kenefick, Kertzer, & Quinn, 2001; Mognoni,

Rossi, Gastaldelli, Canclini, & Cotelli, 2001; Mygind, Andersen, & Rasmussen, 1994; Niinimaa et al., 1978; Saibene, Cortili, Roi, & Colombini, 1989) and the prediction of the field test data to cross country skiing performance (Mahood et al., 2001; Rundell & Bacharach, 1995). A potential problem with field-testing is that it is difficult to control the factors that influence performance (e.g. temperature, inclination, speed, snow conditions, skies) (Noakes, 2000; Larsson & Larsen, 2005). Noakes (2000) states, “There is a dearth of tools to measure accurately human performance in the laboratory. If sports performance cannot be measured frequently with a high degree of precision in the laboratory, then training-induced changes in exercise performance are not quantifiable”. Our study is highly unique in that no research, to our knowledge, has compared a field test versus lab test in disabled cross-country sit skiers.

4.1.1 Field versus Ergometer

4.1.1.1 Peak VO₂

The major finding of this study was the similar VO₂ peak values on the modified double poling ergometer compared to the field test in cross-country skiers with disabilities (sit skiers). Previous research in able-bodied skiers supports these results (Wisloff & Helgerud, 1998). Wisloff and Helgerud (1998) evaluated six able bodied cross country skiers and found no significant difference between a field test and a double poling ergometer protocol for evaluating VO₂ peak (Ergometer: 4.08±0.24 vs. Field: 3.91±0.34 L/min). Because VO₂ is dependent on the amount of oxygen that an individual can be stimulated to extract and use in a specific group of muscles (Thoden, 1991, p.108) similar

VO₂ values were expected due to the similarities in movement patterns between the ergometer and field tests. Based on the perception of the athletes, the sit-ski ergometer was considered to be very specific for cross-country sit skiing. A future study to evaluate whether muscle recruitment is similar between the lab and field protocols could involve the use of electromyography to confirm that muscle usage is similar.

4.1.1.2 Heart Rate and Oxygen Pulse

Peak heart rate was significantly higher during the ergometer protocol compared to the field test. Wisloff and Helgerud (1998) found similar results in able-bodied skiers. A possible mediating factor that may have affected peak heart rate may have been the continuous resistance during the double poling ergometer protocol versus the varying speeds and tempos during the field test. The field-testing course was designed to simulate an actual race with varying inclinations and turns, while the ergometer protocol maintained a constant resistance to the athlete. Therefore, the athletes may not have been able to reach their peak heart rate during the field tests due to short recovery periods (down hills and turns) throughout the testing course. There are two possible explanations for the similar VO₂ responses and a lower heart rate response during the field test. From the Fick equation, VO₂ is the product of cardiac output (heart rate multiplied by stroke volume) and arterial-venous oxygen (A- VO₂) difference; therefore, there may be a difference in oxygen extraction at the muscle (A- VO₂ differences) or stroke volume responses between protocols. Oxygen pulse, which denotes the oxygen utilization per heart beat (Bhambhani et al., 2001) correlates with stroke volume ($r=0.84$) but not with A- VO₂ difference ($r=0.15$) (Bhambhani et al., 1994). The results of our study found no

significant difference in peak oxygen pulse between protocols; therefore, it could be predicted that stroke volume was not different. The lower peak heart rate accompanied by a similar peak VO_2 during the field compared to ergometer test may therefore be explained by a higher A- VO_2 difference during the field test. As mentioned above, the field test involves intermittent contraction during the skiing course as one skis and then recovers through down hills and turns; whereas the ergometer test involves more continuous muscle contractions against the resistance of the ergometer. This may allow for greater blood flow to the muscles during the field test (as muscle recovers between contractions during down hills or turns), permitting a greater extraction of oxygen at the muscle from the blood, which would be reflected as a greater A- VO_2 difference. Future research is needed to examine this hypothesis with direct measures of arterial and venous blood across muscle.

4.1.1.3 Pulmonary Ventilation

The results of our study showed no significant differences in peak minute ventilation between protocols, which are contradictory to previous results. Wisloff and Helgerud (1998) found significantly higher peak minute ventilation during the ergometer protocol. This may have been due to the differences in sit skiing athletes versus standing skiers. However, Wisloff and Helgerud (1998) stated that their results were unexpected, as they found no significant difference in either VO_2 or breathing frequency between the two tests. They concluded that lower peak minute ventilation in the field test might reflect that peak VO_2 can be reached without reaching peak minute ventilation. Our respiratory rate results are in support of Wisloff and Helgeruds (1998) data. We found no significant

difference in respiratory rate between tests. These results were expected due to the similar sitting positions in the sled, similar minute ventilations, and similar VO_2 values between the protocols (Leirdal et al., 2006; Wisloff & Helgeruds, 1998).

4.1.1.4 Blood Lactate and Respiratory Exchange Ratio

Anaerobic energy is supplied via glycolysis and breakdown of phosphocreatine (PCr) stores. PCr stores quickly deplete within the 1st minute of exercise. Glycolysis is the breakdown of glucose resulting in the production of ATP, pyruvate, lactate, and H^+ . It was hypothesized that blood lactate and respiratory exchange ratio would be similar between protocols. However, the results of this study demonstrated significantly higher values during the double poling ergometer protocol. These results suggest an increased anaerobic and carbohydrate utilization during the ergometer protocol. Blood lactate and respiratory exchange ratio may be potentially influenced by several factors such as diet, time of day, and temperature (Roberg & Roberts, 1996). Both tests were performed at similar times of the day. Although diet composition and water intake were not controlled before tests, it can be considered similar for both tests since all subjects belonged to the same training center where nutrition and hydration of athletes were carefully managed. Athletes at camp were supplied and ate the same breakfast each morning before testing. Other possible mediating factors, as mentioned earlier, may be the differences between the field test and ergometer protocol. The field test allowed small recovery periods which may have affected lactate results, by allowing increased lactate clearance through increased blood flow. However future research is needed to confirm these hypotheses.

One mediating factor that may have an effect on all metabolic and cardiovascular values measured is temperature. The difference in temperature between the laboratory condition (21°C) and field test (-8 °C) in the present study could have potentially influenced results during exercise. During exercise in the cold, central blood volume may increase due to peripheral vasoconstriction causing blood to be directed centrally in an attempt to warm the core. This may result in a greater venous return, higher stroke volume and lower heart rate (Rowel, 1986). Faulkner and colleagues (1981) reported a significant reduction in endurance performance in well-trained cross-country skiers during abnormally low (-28°C) ambient temperatures compared to normal conditions. Patton and Vogel (1984) found that time to exhaustion at -20°C was reduced by 40.2% compared to time to exhaustion at 20°C, however they found no significant difference in peak oxygen uptake. Studies examining oxygen consumption have demonstrated equivocal results. For example, Therminarias and colleagues (1989) demonstrated a higher peak VO_2 response in the cold condition. These results were partially explained by the greater exercise intensity performed by some of the subjects, but also by shivering thermogenesis produced by muscles not involved in muscular exercise (Therminarias et al., 1989) and catecholamine secretion. Quirion and colleagues (1989) found contradictory results, they demonstrated significantly lower peak VO_2 values during cold (-20°C) exposure compared to warmer conditions (0°C and 20°C). Quirion and colleagues (1989) found that exercise intensities were more tiring in the cold situations than in the warm environment, leading to an earlier perception of fatigue in the cold condition. They suggest that the net efficiency of exercising in the cold is lower than under normal conditions. Our study found no difference in peak VO_2 between conditions. Results may

vary based on the intensity of the cold, exercise duration, and acclimatization. Studies have shown that humans who are repeatedly exposed to cold air become acclimatized by a reduced thermal discomfort, reduced cold sensation and a lower shivering threshold (Bruck et al., 1976; Rennie et al., 1962). The sit-skiers were tested in normal cold conditions and demonstrated no signs of discomfort during the testing.

Previous studies examining the effects of heart rate responses to cold have also shown varying results. Sandsund and colleagues (1998) found no difference in heart rate during maximal exercise at -15°C compared to 23°C. A study by Schmidt and Bruck (1981) support our findings, demonstrating a reduction in heart rate after pre-cooling. They suggest that the cold causes an increased venous tone, accompanied by enhanced venous return and stroke volume at lower skin temperatures. Our results demonstrated a lower heart rate during the cold field condition. However, our study measured stroke volume indirectly by oxygen pulse. Oxygen pulse was similar between protocols, suggesting similar stroke volumes (Bhambhani, et al., 1994).

Lactate may also be affected by temperature (Sandsund, et al., 1998; Therminarias, et al., 1989); however research has been controversial (Therminarias et al., 1989). Acute exposure to a cold environment has been shown to increase plasma free fatty acids (Himms-Haggen, 1967) and increase lactate concentrations (Lucas et al., 1980), which have been partially linked to an elevation in plasma catecholamine concentrations. Swimming in cold water resulted in a higher blood lactate when compared to warm water (Galbo et al., 1979). Similarly, Quirion and colleagues (1989) found significantly higher

lactate values during an incremental cycle test at -20°C, compared to 0°C and 20°C. In subjects performing prolonged exercise in cold air (5°C) compared to 20°C, there was no significant difference in blood lactate concentrations (Dolny & Lemon, 1988). However, Thermanias and colleagues (1989) found lower lactate levels during an incremental cycle test in the cold condition (-2°C) compared to a warm condition (24°C), which support our findings. They suggest that the lower lactate concentration during the cold condition could have been due to a decrease in anaerobic glycogenolysis rate in the working muscles, secondary to an increase in oxygen delivery. A cutaneous vasoconstriction and a reduction in skin blood flow occur during cold exposure, possibly increasing blood flow to the working muscles. A second possible explanation is due to an increase in lactate utilization. The major sites of lactate removal are the heart, the liver and skeletal muscle. An increase in liver blood flow may have occurred during the cold condition, but lactate appears mainly to be a substrate of some importance for resting, working, and shivering muscles (Brooks, 1986; Stanley et al., 1985). It may be hypothesized that during the cold condition at heavy exercise intensities, when the arterial lactate increases, a part of the lactate production is consumed by shivering muscles. Therefore, the significantly higher blood lactates during the laboratory test (21°C) compared to the field test (-8°C) in our study may be due to an increase in blood flow and lactate utilization.

4.1.2 Sit Skiing versus Standing Skiing

Upper body VO₂ peak values in able-bodied skiers have approached whole body VO₂ max (Rusko, 2003). The highest values for men and women skiers on the double poling

ergometer have been 70-75 ml/kg/min and 60-65 ml/kg/min, respectively. The skiers in our study had significantly lower relative VO_2 peak values (males: 28-45 ml/kg/min; females: 27-40 ml/kg/min). However, these results can be explained by the amount of active muscle mass (Holmberg, 2006). As mentioned previously, double poling is typically thought of as primarily upper body but in fact utilizes large amounts of energy and muscle mass from the legs (Holmberg, 2006). Previous research in able-bodied elite skiers has also demonstrated higher peak heart rates in able-bodied skiers compared to sit skiers (185 vs. 173 beat per minute, respectively) (Rusko, 2003). These results may help to explain the lower VO_2 peak values (using the Fick Equation: $\text{VO}_2 = (\text{HR} \times \text{SV}) \times \text{AVO}_2\text{-difference}$).

Elite endurance trained able bodied athletes have shown an increase in minute ventilation from 6 L/min at rest to 200 L/min in extreme cases during exercise (Astrand & Rodahl, 1986; Rusko, 2003) and cardiac outputs up to 40 L/min. In elite endurance athletes the cardiovascular and muscular adaptations to training have been shown to reach exceptional levels and ventilation demands during short-term maximal exercise occasionally exceeding the maximal capability to develop an appropriate amount of alveolar ventilation (Dempsey et al. 1984; Hopkins & McKenzie 1989; Powers et al. 1988, 1989), thus decreasing the extraction of oxygen due to the shortened transit time of the blood in the alveolar capillaries. During maximal exercise the oxygen consumption of respiratory muscles may be 5-10% of VO_2 max and respiratory muscles may also produce lactate during sub maximal exercise in able-bodied skiers (Rusko, 2003). If lung ventilation during ski racing is close to an individual's maximal voluntary ventilation, the

respiratory muscles may fatigue. The inability to attain a high VO_2 peak and maximal ventilation after the race compared to before, may be caused by fatigue of the respiratory muscles. During cross-country skiing the ability to keep up high ventilation and to resist respiratory muscle fatigue may therefore be a very important determinant of race performance (Rusko, 2003). The athletes in our study had much lower peak ventilations (102 ± 33 L/min) compared to elite able-bodied cross-country skiers (200 L/min) (Rusko, 2003). Previous research in wheelchair paraplegic athletes supports our results, demonstrating lower minute ventilations (Flandrois et al., 1986; Hooker et al., 1993). These studies suggest that the lower ventilation values are related to impaired innervations of some of the respiratory muscles. Future research is needed to examine the oxygen utilization, muscle blood flow, and innervations of respiratory muscle of elite sit-ski athletes, as the low ventilation may be a limiting factor to performance.

Research examining peak lactate values in able-bodied skiers is quite variable and greatly depends on the duration, intensity, and individual training status. Research examining blood lactate values after the Finish championships in the year 2000 found large variations (women 10km race ranged from 9 to 15 mmol/L and men 15 km race from 10 to 17 mmol/L). Results from our study found ranges for women from 4.7 to 9.4 mmol/L and 8.1 to 13.7 mmol/L for men during the field test. The women had much lower results whereas the men had slightly lower results than those found in the Finish skiers. These results can be explained by the amount of active muscle mass able to produce lactate; furthermore the females in our study had on average higher lesions (therefore less

innervated muscle mass) compared to the males, which may explain the lower lactate values in the female subjects in our study.

4.1.3 Physiological Measures and Performance

There were no statistically significant correlations between any physiological measures and performance. Performance was assessed as an athlete's personal best time in a 5km race. Although, there were no statistically significant correlations, peak absolute/relative VO_2 and oxygen pulse demonstrated the highest correlations, providing further evidence that cross country sit skiing is a highly aerobic activity. This is in support of several studies, which have demonstrated a high aerobic contribution in able-bodied cross-country skiing (Astrand & Saltin, 1961; Bioldeau, Roy, & Boulay, 1991; Doyon, Perry, Abe, & Hughson, 2001; Hoffman & Clifford, 1990; Karvonen, Kubica, Kalli, Wilk, & Krasicki, 1987; Karvonen et al., 1989; MacDougall, Hughson, Sutton, & Moroz, 1979; Rusko, 2003). Future research is warranted to verify these results with a larger sample size and to examine which physiological variables predict performance in a variety of specific racing distances (2.5, 5, 10, and 15 km races).

4.3 Limitations

There were several limitations to this study. The major limitation was the small sample size due to the uniqueness of this population. This small sample size greatly increases the chance of a type II error, that is, the chance of accepting the null hypothesis when the research hypothesis is actually true ("false negative"). To test for the likelihood of a type II error, a power calculation was done to assess the predicted subject number needed to

demonstrate a significant difference. A power of 80% with an alpha level of 0.05 was used. The results suggested 105 and 65 subjects to determine a significant difference in relative and absolute VO_2 values, respectively, demonstrating a weak chance of a type II error. However, for peak VE and oxygen pulse, a subject number of 17 and 28, respectively, were predicted to demonstrate a significant difference. This suggests a possible chance of a type II error. Furthermore, a small sample size may be vulnerable to an outlier affecting the results. Based on the individual results of this study there seems to be one potential outlier, see figure 3.2 (B), 3.3 (B), and 3.5 (B). However, when the results were re-examined with this subject removed, there was no difference in the results, except heart rate became non-significant ($p=0.07$) between protocols. Another limitation includes the reliability of the ergometer, which was not assessed. The results of this study need to be taken with caution. Future research is needed to examine the test-retest and intraclass correlation coefficient for reliability of this instrument.

4.4 Recommendations for Future Research

With the use of this ergometer future randomized controlled studies with a larger sample size can be used to monitor physiological responses in elite sit ski athletes. Further research is needed to explore which physiological and biomechanical variables are important to predict performance at varying race distances in sit-skiing, to determine the extent to which sit ski performance is altered by different training programs, and to the specific physiological adaptations which explain training induced changes in athletic performance (Noakes, 2000). Furthermore, future research is needed to explore A- VO_2 difference directly through blood measurements, or using near infrared

spectrophotometry to estimate oxygenation over muscle during the different protocols.

Future research is also needed to examine the oxygen utilization, muscle blood flow, and innervations of respiratory muscles of elite sit-ski athletes, as the low ventilation may be a limiting factor to performance. Due to the low peak ventilation found in these subjects, future research is needed to examine the effects of a respiratory muscle-training program on sit-ski athletes.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Success in cross-country skiing requires genetic endowment combined with specific physiological traits (Brooks et al., 2000; Williams, 1995). One surrogate associated with cross-country skiing performance is maximal oxygen consumption ($\text{VO}_2 \text{ max}$) (Baumgartl, 1990; Bergh, 1987; Berg & Forsberg, 1992; Bilodeau et al., 1996; Ingjer, 1991; Karlsson, 1984; Ng et al., 1988; Niinimaa, Dyon & Shephard, 1978; Rundell & Bacharach, 1995; Rusko, 1992; Staib, Joohee, Caldwell, Rundell, 2000). $\text{VO}_2 \text{ max}$ is often measured in a laboratory setting using an ergometer, due to the technical problems related to testing in the field (Haug et al., 1999; Noakes, 2000; Thoden, 1991, p. 118; Verges et al., 2003). The most common ergometers used to evaluate athletes include treadmills, cycle ergometers, and arm crank ergometers (Haug et al., 1999; Verges, et al., 2003). Testing for sports other than running or cycling, therefore, lack specificity when using these ergometers (Allin & Lockwood, 2004; Mygind et al 1991; Wisloff & Helgerud, 1998)

This study was performed to compare physiological variables (i.e. oxygen consumption, blood lactate, heart rate, respiratory exchange ratio) on a sport specific double poling ergometer, which has recently been modified for sit skiers to a field test for the same skiers. Three male and four female athletes from the Canadian National / Developmental team (17-54 years of age, ranging in ability from a complete T7 spinal injury to cerebral

palsy) completed a field test and a double poling ergometer protocol separated by at least 24 hours. Both protocols consisted of three maximal sets of skiing of three minutes duration per set separated by approximately one and a half minutes rest. A wireless metabolic system (Sensormedics, VmaxST or Cosmed, K4b²) and heart rate monitor were used to measure physiological responses during each test. Arterialized blood lactate was measured before and after each set and for 15 min post exercise. There were no significant differences between the field and ergometer tests for peak VO₂. However, significantly higher peak heart rate and respiratory exchange ratio were found during the double poling ergometer protocol. There were no significant differences in blood lactate at baseline and after set 1. However, a significantly higher peak lactate was found after set 2 and set 3.

5.2 Conclusions

Results of this study suggest that the double poling ergometer is similar to a field test for evaluating peak VO₂ in elite cross country sit skiing athletes; however, the ergometer test involves a higher heart rate and a greater contribution from anaerobic metabolism.

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APPENDICES

Appendix A Classifications

International Paralympic Nordic Cross Country Skiing Committee-2006

Sit-Skiing Classifications:

- **LW 10**
Athletes eligible for class LW 10 are those with disabilities in the lower limb(s) and the trunk. The athlete has no functional abdominals or extensors when sitting with proper strapping on the test table or when using his own equipment. The athlete will require arm support when sitting with proper strapping on the test table. No buttock sensibility.
- **LW 10, 5**
Athletes eligible for class LW 10.5 are those with disabilities in the lower limb(s) and the trunk. The athlete has some upper abdominal and extensor muscles, or lower motor function with spinal fusion / scoliosis, or higher injury level with incomplete spinal cord injury meeting the criteria of the profile. The athlete will sit statically without arm support when sitting with proper strapping on the test table. No buttock sensibility.
- **LW11**
Athletes eligible for class LW 11 are those with disabilities in the lower limb(s) and with abdominal and extensor trunk muscles with contact with the pelvic. No functional hip muscles and no buttock sensibility. The athlete will sit on the tilt table with proper strapping without arm support and perform some of the functional tests.
- **LW11, 5**
Athletes eligible for class LW 11.5 are those with disabilities in the lower limb(s) and near to normal trunk muscles, some functional hip flexion and loss of sensibility in buttock(s) and back of thigh(s).
- **LW12**
Athletes eligible for class LW 12 are those with disabilities in the lower limbs and with normal trunk muscles, near to normal hip flexion and with normal buttock sensibility.

Appendix B Ethics: Certificate of Approval



Certificate of Approval

PRINCIPAL INVESTIGATOR	DEPARTMENT	Bio #
Philip D. Chilibeck	Kinesiology	06-69

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT

National Training Site - Canmore Alberta

Saskatoon SK

SUB-INVESTIGATOR(S)

Bruce Craven

Carol Rodgers

STUDENT RESEARCHER(S)

Scott Forbes

SPONSORING AGENCIES

OWN THE PODIUM, VANCOUVER OLYMPIC ORGANIZING COMMITTEE

TITLE:

Validation of an Ergometer for Cross-Country Skiers with Disabilities

ORIGINAL APPROVAL DATE

30-Mar-2006

CURRENT EXPIRY DATE

01-Mar-2007

APPROVAL OF

Protocol and consent form as submitted

CERTIFICATION

The University of Saskatchewan Biomedical Research Ethics Board has reviewed the above-named research project at a full-board meeting (any research classified as minimal risk is reviewed through the expedited review process). The proposal was found to be acceptable on ethical grounds. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to this research project, and for ensuring that the authorized research is carried out according to governing law. This Approval is valid for the above time period provided there is no change in experimental protocol or in the consent process.

ONGOING REVIEW REQUIREMENTS/REB ATTESTATION

In order to receive annual renewal, a status report must be submitted to the Chair for Committee consideration within one month of the current expiry date each year the study remains open, and upon study completion. Please refer to the following website for further instructions: <http://www.usask.ca/research/ethics.shtml>. In respect to clinical trials, the University of Saskatchewan Research Ethics Board complies with the membership requirements for Research Ethics Boards defined in Division 5 of the Food and Drug Regulations and carries out its functions in a manner consistent with Good Clinical Practices. This approval and the views of this REB have been documented in writing.

APPROVED.

Michel Desautels, Ph.D., Chair
University of Saskatchewan
Biomedical Research Ethics Board

Please send all correspondence to:

Ethics Office
University of Saskatchewan
Room 305 Kirk Hall, 117 Science Place
Saskatoon, SK S7N 5C8
Phone: (306) 966-4053 Fax: (306) 966-2069

Appendix C Consent Form

Research Participant Information and Consent Form

Title: Validation of an ergometer for cross-country skiers with disabilities

Sponsor: Own the Podium, Vancouver Olympic Organizing Committee

Names of Researchers: Principal Investigator: Philip D. Chilibeck, Ph.D., College of Kinesiology, University of Saskatchewan, phone: 306-966-1072 or 306-343-6577, Co-investigators: Scott Forbes, B.Sc. (student researcher, supervised by Phil Chilibeck), College of Kinesiology, University of Saskatchewan, phone: 306-966-1123, Carol Rodgers, Ph.D., College of Kinesiology, Phone: 306-966-1061, and Bruce Craven, M.Sc. (Sports Medicine and Science Council of Saskatchewan), Phone: 306-975-0848.

You are being invited to participate in a research study because we want to determine whether your response to exercise is similar between a skiing exercise machine and actual skiing on an outdoor course.

Before you decide, it is important for you to understand what the research involves. This consent form will tell you about the study, why the research is being done, what will happen to you during the study and the possible benefits, risks and discomforts.

If you wish to participate, you will be asked to sign this form. Your participation is entirely voluntary, so it is up to you to decide whether or not to take part in this study. If you do decide to take part in this study, you are free to withdraw at any time without giving any reasons for your decision and your refusal to participate will not affect your relationship with any of the researchers or your coaches. Please take time to read the following information carefully and to discuss it with your family, friends, coaches, and doctor before you decide.

Purpose of the study: The purpose of the study is to compare your responses during exercise on an indoor skiing exercise machine and actual skiing on an outdoor course. If exercise responses are similar it will validate the use of the indoor exercise machine for training during the off-season.

Possible benefits of the study: You will get an assessment of your fitness level by participating in the study and the results of the study will be useful to athletes and coaches for determining whether the indoor skiing machine is useful for off-season training. These benefits are not guaranteed.

Procedures:

If you agree to be in this study the following will happen:

You will participate in an exercise test on an indoor exercise machine and then on a separate day will perform skiing on an outdoor course. The order of the two tests will be randomized, that is, the test that is done first will be determined by chance (i.e. by a computer). The ski machine involves pulling on handles that are connected to ropes

which are connected to a resistance by a pulley system. This is designed to simulate actual skiing.

Each test will involve skiing over a 1000 m course, repeated 3 times, with a one-minute rest between repeats (this is simulated on the indoor exercise machine – the distance output is given on a display mounted on the machine). You will be required to ski at maximal pace during each test.

We will be assessing blood lactate levels before, during and after the exercise tests. Lactate is a metabolite that is produced in muscle during high-intensity exercise. Blood lactate level will be assessed before exercise, after each 1000 m repeat, and at the following times during recovery (i.e. after the 3 x 1000 m repeats are completed): 1, 3, 5, 7, 10, 15, 30, 45, 60, 90, 120 minutes. Each time, lactate is assessed from a drop of blood collected from the ear lobe. A small lancet is used to poke your ear to allow collection of a single drop of blood. Usually the ear only has to be “poked” a few times because repeated blood drops can be obtained by rubbing the poked area with an alcohol swab.

During the exercise tests, and for 120 minutes after the tests, oxygen consumption will be measured with a portable gas analyzer. This allows us to assess your physical fitness (i.e. the higher your oxygen consumption, the higher your level of aerobic fitness). You will be required to wear a light-weight pack around your trunk which is connected by a mask to your mouth and nose. Simultaneously, heart rate will be assessed by having you wear a heart rate monitor around your chest. Blood pressure will be monitored during recovery at 1, 5, 10, 30, and 60 minutes.

Foreseeable risks, side effects or discomfort:

The exercise tests will be at maximal intensity and therefore will result in some discomfort and muscle fatigue.

The finger pricks from for the blood lactate testing will involve some discomfort/pain and may leave bruising. In rare instances, infection may develop at the site of the finger prick, but care will be taken to prevent this from occurring.

Wearing the face mask during the exercise tests may be uncomfortable.

There may be unforeseen and unknown risks during the study, or after the study has been completed.

Alternatives to this study:

You do not have to participate in this study to have your fitness levels assessed. Your fitness levels will be assessed at other times during your regular training program.

Research-Related Injury: There will be no cost to you for participation in this study. You will not be charged for any research procedures. In the event you become ill or

injured as a result of participating in this study, necessary medical treatment will be made available at no additional cost to you. By signing this document you do not waive any of your legal rights.

Confidentiality: While absolute confidentiality cannot be guaranteed, every effort will be made to ensure that the information you provide for this study is kept entirely confidential. Your name will not be attached to any information, nor mentioned in any study report, nor be made available to anyone except the research team. It is the intention of the research team to publish results of this research in scientific journals and to present the findings at related conferences and workshops, but your identity will not be revealed.

Voluntary Withdrawal: Your participation in this research is entirely voluntary. You may withdraw from this study at any time. If you decide to enter the study and to withdraw at any time in the future, there will be no penalty or loss of benefits to which you are otherwise entitled.

If you choose to enter the study and then decide to withdraw at a later time, all data collected about you during your enrolment in the study will be retained for analysis.

If you have questions concerning the study you can contact Dr. Philip Chilibeck at 306-966-1072, 306-343-6577, or 306-230-3849 (24 hour cell). All numbers can be called collect if you are phoning long distance.

If you have questions about your rights as a research subject, you can contact the Office of Research Services at the University of Saskatchewan at 306-966-4053. Again, this number can be called collect if you are phoning long distance.

By signing below, I confirm the following:

- I have read or have had this read to me and understood the research subject information and consent form.
- I have had sufficient time to consider the information provided and to ask for advice if necessary.
- I have had the opportunity to ask questions and have had satisfactory responses to my questions.
- I understand that all of the information collected will be kept confidential and that the result will only be used for scientific objectives.
- I understand that my participation in this study is voluntary and that I am completely free to refuse to participate or to withdraw from this study at any time without changing in any way the quality of training that I receive or my relationship with coaches or members of the research team.
- I understand that I am not waiving any of my legal rights as a result of signing this consent form.
- I understand that there is no guarantee that this study will provide any benefits to me.
- I have read this form and I freely consent to participate in this study.

- I have been told that I will receive a dated and signed copy of this form

Participant's Signature: _____ Date: _____

Individual conducting the consent process: _____

Date: _____

Appendix D Example of a Subject Information Sheet

Monday, April 3rd, 2006

Subject Number One:

8:00: Arrive at field ready to go.

8:05: Start Warm up for 15 minutes

8:25: Test Will Begin

3 X 3 minutes (1 minute recovery) = 9 minutes

8:50 post exercise (15 minutes with VO₂)

Lactate will be taken at 1 (8:51), 3 (8:53), 5 (8:55), 10 (9:00), 15(9:05).

Subject Number Two:

9:30 Arrive at field ready to go.

9:35 Start Warm up for 15 minutes

9:55 Test Will Begin

3 X 3 minutes (1 minute recovery) = 11 minutes

10:20 post exercise (15 minutes with VO₂)

Lactate will be taken at 1 (10:21), 3 (10:23), 5 (10:25), 10 (10:30), 15(10:35).

Subject Number three

11:00: Arrive at field ready to go.

11:05: Start warm up for 15 minutes

11:25: Test will begin

3 X 3 minutes (1 minute recovery) = 11 minutes

11:50: Post exercise (15 minutes with VO₂)

Lactate will be taken at 1 (11:51), 3 (11:53), 5 (11:55), 10 (12:00), 15(12:05).

Protocol for Subjects:

1. Please come prepared to do a field test (3 X 3' (approx. 1000m) with 1 minute recovery).
2. Time is tight and therefore we will have to move quickly, if you need a longer warm up than 15 minutes please come early.
3. Lactate will be taken regularly for the first 15 minutes post exercise, which means you, must stay close to the lab. Please bring warm clothes to wear after your test as you will not be able to return to your room during this time.
4. Please resist from caffeine and vigorous exercise (6 hours prior). This is a maximal test so be well hydrated.